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Infant vaccination coverage in 2005 and predictive factors for complete or valid vaccination in Flanders, Belgium: an EPI-survey

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Abstract

To assess changes in infant vaccination coverage in Flanders since 1999, an EPI-survey was performed in 2005. The parents of 1354 children aged 18–24 months were interviewed at home and the vaccination documents were checked. Several factors possibly related to vaccination status were examined with parametric and non-parametric methods. The coverage rate of recommended vaccines, i.e. poliomyelitis, tetanus–diphtheria–pertussis, H. influenzae type b (Hib), hepatitis B, measles–mumps–rubella (MMR) and meningococcal C, reached at least 92.2%, which is a significant rise for MMR, hepatitis B and Hib since 1999. The vaccinating physician, the employment situation of the mother and the family income were significant predictive factors for having received all recommended vaccine doses (complete schedule), also when considering only doses that were according to minimal age and interval criteria (valid schedule).

Keywords: Vaccine coverage; Risk factors; Infants

1. Introduction

Universal vaccination of infants has been an important tool in controlling infectious diseases in the past century. To attain elimination, vaccination strategies should aim at achieving and maintaining a high vaccination coverage [1,2].

In Flanders (Belgium) almost all vaccines that are recommended by the National Health Council, are offered free of charge by the government. Only polio vaccination is mandatory by law. Parents can choose to have their child immunised in a "well baby clinic", which is a public organisation, or by their private general practitioner or paediatrician. All vaccinators have a permanent supply of the vaccines that are offered for free. In well baby clinics, also administration of vaccine is free of charge. Vaccinators provide and complete a vaccination document to be kept by the parents. A web-based database for the ordering of vaccines and registration of vaccinations is recently being developed.

In 1999, an EPI-based survey to measure infant vaccine coverage at 18–24 months-of-age in Flanders demonstrated insufficient coverage for measles–mumps–rubella vaccine (MMR) (83.4%), hepatitis B vaccine (HBV) (68.4%) and H. influenza type b vaccine (Hib) (73.9%) [3,4]. Since this survey, the recommended schedule has changed markedly. Firstly, the start of primary vaccination was advanced from 3 to 2 months-of-age in 2000. Secondly, the mandatory oral polio vaccine was replaced by the inactivated vaccine (IPV) and included in a combination vaccine with tetanus–diphtheria–pertussis (DTP) in 2001. Afterwards, in 2002, the recommended age for the MMR vaccine was advanced to 12 months-of-age to be administered simultaneously with the newly introduced conjugated serogroup C meningococcal vaccine (MenC) and the Hib vaccine

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Table 1
Recommendations for infant vaccination schedule in 2003 and 2004, combined with recommendations for minimal acceptable age per dose, by the National Health Council

Recommended age (month)	2003					2004		
	DTPa–IPV	Hib	HBV	MMR	MenC	Hexavalent	MMR	MenC
2	6 weeks	6 weeks	–	–	–	6 weeks	–	–
3	10 weeks[a]	10 weeks[a]	Birth	–	–	10 weeks[a]	–	–
4	14 weeks[a]	14 weeks[a]	4 weeks[a]	–	–	14 weeks[a]	–	–
12–13	–	–	–	12 months	12 months[e]	–	12 months	12 months[e]
13–18	12 months[b]	12 months[c]	6 months[d]	–	–	12 months[b]	–	–

All recommended vaccines were offered free of charge. A different combination vaccine was available free of charge in 2003 compared to 2004. DTPa, diphtheria–tetanus–acellular pertussis vaccine; IPV, inactivated poliomyelitis vaccine; Hib, H. influenzae type b vaccine; HBV, hepatitis B vaccine; MMR, measles–mumps–rubella vaccine; MenC, conjugated meningococcal C vaccine; hexavalent, IPV–DTPa–Hib–HBV combination vaccine.
[a] Additionally, a minimal acceptable interval of 4 weeks with the previous dose has to be respected.
[b] Additionally, a minimal acceptable interval of 6 months with the previous dose has to be respected.
[c] Additionally, a minimal acceptable interval of 8 weeks with the previous dose has to be respected.
[d] Additionally, a minimal acceptable interval of 8 weeks with the previous dose and 16 weeks with the first dose has to be respected.
[e] For a single dose schedule.

was made available free of charge. Finally, a hexavalent DTP–IPV–Hib–HBV vaccine was introduced to replace the separate DTP–IPV + Hib en HBV vaccines in 2004. As routine collection of vaccination data was not yet in place in Flanders, a new and larger survey was performed in 2005 in infants aged 18–24 months to monitor changes in vaccine coverage. The vaccination schedules recommended by the National Health Council that were applicable for this cohort are summarised in Table 1. All mentioned vaccines were free of charge during the period covered by the survey. Criteria to assess the validity of vaccine doses (in terms of minimum age and intervals between doses) are also summarised in Table 1.

A number of characteristics have been found to be related to vaccination coverage in industrial countries, such as parental education, ethnicity, age, marital and working situation, birth order of the child, medical problems, side effects of vaccination, vaccine provider and having a vaccination card [3,5–18]. Therefore, they were also examined in this survey.

This article presents the current vaccine coverage in infants aged 18–24 months in Flanders and the predictive factors that were identified for complete vaccination. Additionally, we assessed the validity of each vaccine dose according to minimum age and interval parameters, and we evaluated risk factors for not having received a complete schedule with only valid doses independently. Timeliness of vaccination with regard to maximal ages will be addressed in a different publication.

2. Methods

2.1. Survey design

We used an EPI-based two-stage cluster survey design, which had also been used for the 1999 survey [5,6,19]. To calculate the sample size, the margin of error for the 95% confidence interval was set at 2.5%. Coverage rates of approximately 90% and a design effect of two were assumed, based on the findings of the 1999 study, which resulted in a sample size of 1500 infants.

Using EPI-methodology, we firstly selected a population-proportionate sample of 125 clusters in 107 municipalities, stratified over the five Flemish provinces proportionally to the size of their birth cohort in 2003. In a second stage, the National Register randomly selected 12 infants per cluster, who were born between June 30th and November 15th of 2003. This Register only contains persons who are officially registered as resident in Flanders. For each cluster, four extra children were selected to be able to replace families that could not be reached or were not able to take part due to language problems. The selected families received a brief information letter announcing the visit of an interviewer. Trained interviewers visited them at home between May 10th and July 31st of 2005. After having obtained written informed consent from a parent or caretaker, they transcribed the vaccination data from the vaccination card, asked which physician administrated each of the vaccines and requested permission to obtain missing data from the medical file. Using a standardised questionnaire, the interviewer also retrieved additional information from the parents. Socio-demographics collected on family level were the birth dates of all family members, single parentage and the family income per month. For each parent, the educational level, employment status as well as their own country of birth and that of their parents were registered. Moreover, history of side effects after any vaccination, the number of past illness episodes of the child, the preferred physician in case of illness and use of day-care were asked for. The degree of urbanisation of each community in the sample was obtained via the National Institute of Statistics. At least three attempts to reach a family (two home visits and a telephone contact) had to be made before a replacement address in the same cluster could be used. If parents were reached but refused to participate, the child was not replaced to limit the

risk of selection bias, as refusal could be linked to a negative attitude against vaccination. The study was approved by the Antwerp University Hospital Ethics Committee and by the National Privacy Commission.

2.2. Definitions

For the analysis of risk factors, two main outcome factors were defined, according to the number of doses in the recommended vaccine schedule and the guidelines on minimum acceptable age per dose and minimum acceptable interval between doses approved by the National Health Council summarised in Table 1 (http://www.health.fgov.be). These guidelines are almost identical to those approved by the Advisory Committee on Immunisation Practices of the United States of America [20,21]. Firstly, we defined a complete schedule as four doses for IPV, DTP and Hib, three doses for HBV and one dose for MMR and MenC. Secondly, we defined a valid schedule as a complete schedule strictly respecting all minimum age and interval parameters. As a consequence, a schedule was considered invalid if not all recommended doses had been given or if doses had been excluded for being administered too early. For MenC, three doses with an interval of at least 4 weeks, starting at the age of 8 weeks or later, was also considered a valid schedule, according to recommendations from the manufacturer. The main vaccinator was defined as the physician who administered the highest number of vaccine doses, not counting DTP and Hib doses because they were usually given in a combined vaccine with IPV. The ethnicity of a child was categorised as non-Belgian if at least one of the parents or grand-parents were born outside Belgium, and as non-European if at least one of them was born outside Europe.

2.3. Statistical analysis

All analyses were adjusted for the survey design described above. Weighting was performed for variables having a different distribution in the study sample compared to the reference population. Doses not documented on the vaccination card at home or in a medical file, were considered as not given.

Characteristics associated with either complete or valid vaccination were analysed for each vaccine as well as for the whole schedule. The combination of the expected low occurrence of incomplete vaccination and the large number of characteristics (23 in total) included in the survey is very likely to induce problems of multi-colinearity and sparseness that complicate classical stepwise regression. Therefore, we supplemented logistic regression with non-parametric classification tree analysis and random forests [22–27]. Classification tree analysis constructs disjointed subsets of data, called nodes, following specific splitting rules. This way the characteristics are identified that explain the outcome variable in the best way, i.e. resulting in a tree with the most homogenous end nodes. A random forest analysis summarises the findings of a set of possible classification trees, based on bootstrap samples, which are subsets of the total sample. According to their frequency of appearance as first parent nodes, the variables are ordered into variable importance lists. For this study, binary classification trees were used, where every parent node was split in exactly two child nodes, predicting either complete or valid vaccination. Based on these binary classification trees, variable importance lists were generated for complete and for valid vaccination separately, for each vaccine (IPV, DTP, Hib, HBV and MMR) and for the total schedule as a whole, which means a total of 14 lists. In a next step, from each list a limited number of most important characteristics was selected based on the mean Gini index, which is a measure for how much of the variability in the data is attributed to the according variable. For each vaccine and for the total schedule, a separate logistic regression analysis predicting either complete or valid vaccination was performed thereafter using the variables selected by random forest, resulting in 14 different regression models. Variables were omitted by backward stepwise selection, based on significance level. Associations were considered significant if the p-value did not exceed 0.05. Vaccine coverage analysis and logistic regression were performed with Stata 9 and non-parametric analyses with R 2.3.1.

3. Results

3.1. Study population

Between May 10th 2005 and July 31st 2005, 1476 families with a child aged 18–24 months were visited at home. Two hundreds and twenty-six (15.3%) of them were replacements for families that could not be reached, mainly because they could not be traced or contacted. Among the families visited at home, 117 (7.9%) refused to take part, mainly mentioning reasons as "Not interested" or "No time". Those families were not replaced to limit the risk of selection bias. In addition, data about five children were lost. The main characteristics of the study population are summarised in Table 2. Most socio-demographic parameters were comparable to other data about Flemish children under 3 years-of-age, except for the gender distribution which was 53% girls and 47% boys, compared to 49 and 51% in the reference population. This was adjusted for by weighting, which necessitated the exclusion of five children who were all fully vaccinated, leaving data from 1349 children for analyses.

3.2. Coverage rate of recommended vaccines

The coverage rate per dose is presented in Table 3. The design effect did not exceed 1.4 for any of the vaccine doses. For HBV, the coverage is mentioned up to the third dose as the majority of the children received the 2003 schedule with three doses of HBV. A fourth dose of HBV appeared to be administered to 10.1% (95%CI: 8.2–11.9%) of them. No vaccination could be documented for 12 (1%) children.

Table 2
Main characteristics of sampled children and their parents (Flanders, 2005)

Children's characteristics ($n = 1349$)		
Gender: males (%)	47.1	
Number of siblings (%)		
Only child	36.9	
One other child	42.5	
Two or more other children	20.6	
Main vaccinating physician	See Tables 4 and 5	
Vaccination document present at home (%)	91.2	
Attendance at day-care (%)	73.4	
Professional	57.9	
Non-professional (e.g. grand-parents)	24.8	
Family income	See Tables 4 and 5	
Parents' characteristics	**Father**	**Mother**
Mean age in years (minimum–maximum)	31.9 (19–61)	29.2 (15–49)
Educational level (%)		
Lower than secondary school	21.6	19.2
Secondary school	36.3	31.6
Higher than secondary school	42.9	49.9
Employment status (%)		
Full-time salaried employment	78.7	39.2
Not full-time or freelance	15.4	32.6
Not working	5.9	28.1

For 141 (10.5%) children, one or more of the recommended doses were missing. The majority of children was immunised in well baby clinics (80.9%) or in day-care centres (2.3%). The others were vaccinated privately by their paediatrician (10.9%) or general practitioner (5.3%), and 0.6% received their vaccines abroad. Vaccination coverage in replacements was not statistically different from the whole group.

3.3. Factors related to complete or valid vaccination

The variable importance lists were very similar for all vaccines and for both outcome factors. Fig. 1 presents the result for complete IPV vaccination as an example. The four most important variables in any list were the maternal age, the paternal age, the employment situation of the mother, and the main vaccinator. The next five variables were the province of residence, the maternal educational level, the paternal educational level, the family income and the age of the child. Using a visible cut-off, as proposed by Lunetta et al. [24], the nine variables described above were selected for most of the models. For the models predicting complete vaccination with

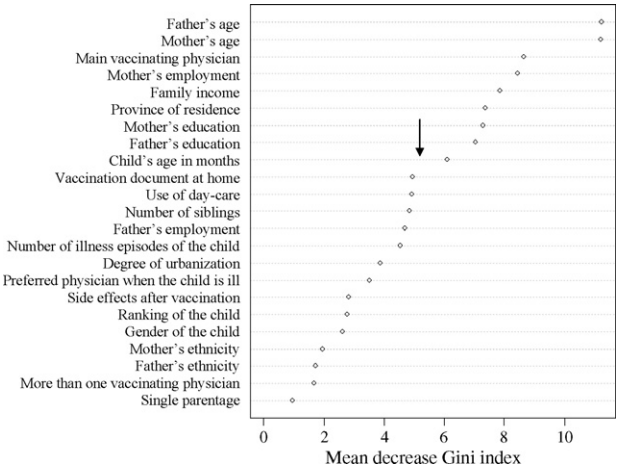

Fig. 1. Variable importance list for completeness of IPV vaccination, by non-parametric random forest analysis. The mean Gini index is a measure for how much of the variability in the data is attributed to the according variable. The cut-off (arrow) represents the point after which the decrease in mean Gini index remains small between two consecutive variables in the list.

DTP, Hib, HBV or MMR, the child's age was not retained. For both MenC models, use of day-care was retained as a 10th factor and for the model predicting valid vaccination, the number of siblings was an eleventh factor.

In a next step, logistic regression models predicting either complete or valid vaccination were constructed with the selections of variables described above. To avoid co-linearity in the logistic regression analysis, correlation between maternal and paternal factors was sought and was found to be significant for age and educational level. It was therefore decided to retain only the maternal age and educational level as a proxy for both parents. Additional analyses showed that the omitted variables did not contribute significantly when added to the logistic regression model.

The final regression models are presented in Table 4 (complete schedule according to the number of doses) and Table 5 (valid schedule, i.e. complete and no doses were given too early according to minimal age and interval criteria). The main vaccinator was significant in all models. Compared to children mainly vaccinated by a paediatrician, children mainly vaccinated by a family physician were less likely to be completely vaccinated. Children vaccinated in a well baby clinic or day-care centre were more likely to receive valid schedules for most vaccines (Table 5), but if validity criteria were not considered, there was only a difference in completeness of HBV schedules (Table 4).

Table 3
Vaccine coverage in infants aged 18–24 months in Flanders in 2005, in percent (with 95% confidence interval) ($n = 1349$)

	IPV	DTPa	Hib	HBV	MMR	MenC
Dose 1	99.0 (98.5–99.5)	98.7 (98.1–99.3)	98.1 (97.4–98.8)	96.9 (95.9–97.9)	94.0 (92.6–95.3)	94.1 (92.8–95.4)
Dose 2	98.6 (97.9–99.2)	98.2 (97.4–99.0)	97.6 (96.7–98.5)	96.1 (94.9–97.3)		
Dose 3	98.2 (97.4–98.9)	97.9 (97.0–98.8)	97.2 (96.3–98.2)	92.2 (90.8–93.7)		
Dose 4	93.1 (91.8–94.4)	93.1 (91.6–94.2)	92.6 (91.2–94.0)			

See Table 1 for vaccine abbreviations.

Table 4
Predictive factors for having received a complete schedule for each recommended vaccine and for the total recommended schedule, from logistic regression analysis

Total sample population	*n*		HBV	IPV	DTPa	Hib	MenC	MMR	Total schedule
	1349	Coverage (%)	92.2	93.1	92.9	92.6	94.1	94.0	88.5
Main vaccinating physician[a]									
Well baby clinic or day-care	1123	OR (95%CI)	**2.7***** **(1.5–4.8)**	1.7 (0.8–3.6)	1.7 (0.8–3.5)	1.7 (1.8–3.5)	1.2 (0.5–2.8)	**2.3*** (1.0–5.1)	**3.0***** **(2.0–4.7)**
Family physician	68	OR (95%CI)	**0.2***** **(0.1–0.5)**	**0.2***** **(0.1–0.5)**	**0.2***** **(0.1–0.4)**	**0.1***** **(0.05–0.3)**	**0.2***** **(0.05–0.4)**	**0.3**** **(0.1–0.7)**	**0.3***** **(0.2–0.6)**
Baseline: paediatrician	146	OR	1	1	1	1	1	1	
Mother's employment situation									
Not full-time or freelance	436	OR (95%CI)			1.2 (0.7–2.1)	1.3 (0.7–2.2)			
Full-time salaried	521	OR (95%CI)			**2.3*** **(1.2–4.6)**	**2.4**** **(1.3–4.7)**			
Baseline: not working	374	OR			1	1			
Family income									
Baseline: <€1500 per month	112	OR		1					
€1500–2000 per month	183	OR (95%CI)		1.3 (0.6–2.8)					
€2000–3000 per month	440	OR (95%CI)		**2.9**** **(1.4–6.4)**					
>€3000 per month	339	OR (95%CI)		2.1 (0.9–4.8)					
Unknown income	275	OR (95%CI)		1.4 (0.6–3.4)					

See Table 1 for vaccine abbreviations. Total schedule, all recommended vaccines; OR (95%CI), odds ratio (95% confidence interval). Odds ratios are only presented for significant variables and are adjusted for other factors in the same column.

[a] Only for children who received at least one dose of any vaccine.

* Significant with $p < 0.05$.

** Significant with $p < 0.01$.

*** Significant with $p < 0.001$.

Table 5
Predictive factors for having received a valid schedule for each recommended vaccine and for the total recommended vaccination schedule, from logistic regression analysis

Total sample population	*n*		HBV	IPV	DTPa	HIB	MenC	MMR	Total schedule
	1349	Coverage (%)	88.6	85.5	85.6	86.4	88.3	90.1	74.7
Main vaccinating physician[a]									
Well baby clinic or day-care	1123	OR (95%CI)	**1.8*** **(1.1–2.9)**	**2.1**** **(1.3–3.3)**	**2.1**** **(1.3–3.4)**	**2.1**** **(1.4–3.4)**	**1.9**** **(1.2–2.8)**	1.7 (0.9–2.9)	**2.4***** **(1.7–3.4)**
Family physician	68	OR (95%CI)	**0.2***** **(0.1–0.4)**	**0.3**** **(0.2–0.6)**	**0.4**** **(0.2–0.7)**	**0.3***** **(0.1–0.6)**	**0.4**** **(0.2–0.8)**	**0.3**** **(0.1–0.7)**	**0.3***** **(0.2–0.6)**
Baseline: paediatrician	146	OR	1	1	1	1	1	1	1
Mother's employment situation									
Not full-time or not salaried	436	OR (95%CI)	1.2 (0.7–1.8)	1.1 (0.7–1.7)	1.0 (0.6–1.5)	0.9 (0.6–1.4)			1.1 (0.8–1.5)
Full-time salaried	521	OR (95%CI)	**2.1**** **(1.2–3.4)**	**2.3***** **(1.5–3.6)**	**1.7*** **(1.1–2.8)**	**1.6*** **(1.0–2.5)**			**1.8**** **(1.3–2.4)**
Baseline: not working	374	OR	1	1	1	1			1
Family income[b]									
Baseline: <€1500 per month	112	OR						1	
€1500–2000 per month	183	OR (95%CI)						1.7 (0.7–4.3)	
€2000–3000 per month	440	OR (95%CI)						1.4 (0.6–3.2)	
>€3000 per month	339	OR (95%CI)						1.3 (0.6–3.2)	
Unknown income	275	OR (95%CI)						0.6 (0.3–1.5)	

See Table 1 for vaccine abbreviations. Total schedule, all recommended vaccines; OR (95%CI), odds ratio (95% confidence interval). Odds ratios are only presented for significant variables and are adjusted for other factors in the same column.

[a] Only for children who received at least one dose of any vaccine.

[b] Income was retained in the MMR model due to a significant association between the category "unknown" and each income category except "income < €1500".

* Significant with $p < 0.05$.

** Significant with $p < 0.01$.

*** Significant with $p < 0.001$.

Other significant characteristics were the employment situation of the mother and the family income. Children having a full-time working mother were more likely to receive a valid vaccination schedule as a whole and for IPV, DTP, Hib and HBV vaccines separately (Table 5). When validity criteria were not considered (Table 4), a full-time working mother was a significant factor only for complete DTP and Hib vaccination. The family income was significant for complete IPV vaccination, no dose–response relationship between income and vaccination status was found (Table 4). Income was also significant for valid MMR vaccination, but no significant difference was found between the lowest income category and any of the other income categories (Table 5). When comparing children with unknown family income to categories with a family income of €1500 per month or higher, the latter were more likely to be vaccinated validly, i.e. on or after the first birthday. As income was no predictor for complete MMR vaccination (Table 4), this association should be related to the timing of the vaccination.

To find out if the parents' choice of the main vaccinator could be predicted by the other characteristics from the survey, we decided to perform an additional analysis, applying the same strategy as described above. The variable importance list generated by random forest analysis with the main vaccinator as outcome factor indicated the age of each parent, the employment situation of the mother, the province of residence, the family income, the educational level of each parent, the preferred physician when the child was ill, the age of the child and the use of day-care as most important variables. Logistic regression showed that older mothers ($p < 0.001$) and mothers living in more populated provinces ($p < 0.05$) were significantly more likely to choose a paediatrician as main vaccinator, whereas parents preferring to consult a paediatrician when the child was ill were significantly less likely ($p < 0.05$) to go there for vaccination (data not shown).

4. Discussion

This survey showed an important increase in infant vaccine coverage at 18–24 months age in Flanders in 2005 compared to the survey performed in 1999, especially for MMR (10.6% rise), HBV (23.8% rise for the third dose), and Hib (18.7% rise for the fourth dose) [3,4]. For HBV and Hib, this can be explained by an increase in reimbursement, as they were only partially refunded in the period covered by the 1999 survey but were free of charge in the current study period. Moreover, vaccines that are offered free of charge are ready available at the vaccinator sites in Flanders, whereas partially refunded vaccines have to be bought at the pharmacy and need extra administration to obtain the refunding, which adds logistical barriers for vaccination. The rise of the MMR coverage may be related to changing the recommended age from 15 to 12 months, which advanced this vaccination in the infant vaccination schedule. The need to enhance the MMR coverage has been communicated to the vaccinators after the 1999 survey, which might have had an impact as well. The hexavalent vaccine became available free of charge for all children at some point in their schedule, which might have increased the completeness of the schedules by eliminating the risk of stock break for a single component of the vaccine. The higher participation rate to the services of well baby clinics during the first year of life could have contributed to an increased coverage for several vaccines. The MenC campaign that targeted all children from 1 to 18 years in Flanders between 2002 and 2004 may also have promoted vaccination in general. At least a high MenC coverage in infants was very quickly achieved. For each recommended vaccine a coverage higher than 90% was achieved, which is the current global goal of the WHO (http://www.who.int/vaccines-documents/DocsPDF05/GIVS_Final_EN.pdf), and for MMR the coverage was close to the very high goal of ≥95% formulated in the current WHO European Region Strategic Plan for elimination of Measles and Rubella. Comparison to other European countries is difficult due to differences in the recommended number of doses per vaccine. The coverage of MMR and the fourth dose of DTP reported to the WHO (http://data.euro.who.int/cisid/) in 2004 by Denmark, Finland and the Netherlands exceeded 93%, except for the fourth dose of DTP in Denmark (87%). In Italy, an EPI-survey conducted in 2003 found 95.7% for the third dose of HBV, but only 76.9% for MMR [5]. A large-scale survey performed in the UK in 2002–2003, recorded 3.3% of partially immunised and 1.1% of non-immunised infants at 9 months-of-age for the recommended vaccine schedule as a whole [8].

If non-valid schedules were excluded, the coverage per vaccine dropped with 3.6–7.6%. Validity assessments are rarely performed, though administering vaccine doses too early can impair the immune response to some vaccines [28]. In the majority of the 45 countries they evaluated, Murray et al. found that the officially reported coverage of the third dose of DTP differed more than 20% with the valid coverage rate, that considered only doses given in accordance to the schedule [29]. In the US, excluding invalid doses lowered the coverage per vaccine with 0.7–6.5% [28].

For the statistical analysis, we chose to use non-parametric analysis both as a source of information and as a selection tool for the parametric regression analysis. It is a standard approach to use non-parametric techniques to validate and complement parametric methods, since the latter inevitably rely on model assumptions. Moreover, non-parametric techniques have been used as data mining and variable selection tools, e.g. Moons et al. [30]. However, only logistic regression can demonstrate significance at a 5% level. Therefore, if findings of a non-parametric analysis are confirmed by parametric analysis, the evidence is stronger and the information is more detailed.

The various statistical models used in this study to identify predictive factors for being completely or validly vaccinated, produced similar results. In the logistic regression analysis, the physician who administered most of the vaccine doses was the main predictor of both outcome factors. The work-

ing situation of the mother and the family income were mainly predictive of valid vaccination. Random forest analysis indicated that parental age and education, the province of residence and the age of the child could also be important, but they were not significant in the logistic regression analysis.

Children vaccinated in a well baby clinic, a public health service offering preventive child care free of charge, were significantly more likely to have received a valid schedule than children vaccinated by a paediatrician or a family physician, both private physicians. This could be related to the vaccinators, but also to characteristics of the parents preferring a paediatrician or a family physician for vaccination of their child, or even to characteristics of the child itself, like frequent episodes of illness. Interestingly, in random forest analysis, the most important variables predicting the parents' choice of the main vaccinator were the same as the ones that were found predicting complete or valid vaccination. The amount of illness episodes of the child was not important, neither for the choice of the main vaccinator, neither for prediction of complete or valid vaccination. Unfortunately, regression analysis did not add much useful information. In the 1999 survey in Flanders, the main vaccinator was found to be associated with the educational level of the parents [4]. The vaccine provider was also found to be a significant determinant of vaccination in some US studies [10,11] and physician factors were found important in surveys questioning the reason for non-vaccination [3,18,31].

Our finding that full-time working mothers were significantly associated with complete vaccination is consistent with findings in the UK [8]. Possibly a higher educational level, a higher income, a better access to information or a difference in organising capacities could explain this. The association with the mother's employment was more apparent in the models for valid schedules, where doses given too early had been excluded. This could hardly be due to financial factors, suggesting that other factors related to the employment status should be more important. We would not expect financial barriers, as all recommended vaccines were for free during the study period and the network of well baby clinics, which offer services free of charge, is well spread. Therefore, it was rather surprising to find the family income predicting complete polio vaccination and valid MMR vaccination. However, there was no dose–response relationship and for MMR this finding was only related to the timing of the vaccination. Probably for these vaccines the family income was also a marker of other factors related to the general socio-economic situation of the family that could not be further identified.

Maternal and paternal educational level and age were found to be important in the non-parametric analysis only. In other studies, including a previous study in Belgium [3,6,12,14], low parental educational level was significantly associated with incomplete vaccination and maternal age has been recognised as a factor influencing vaccination elsewhere [6,8,12,13].

Having a single parent, a high number of siblings or having older siblings were not found to be associated to the vaccination status in this study, although they were in other studies [8,11,13–16,18]. This could be due to low financial and practical barriers, as in Flanders vaccinators are available at a large range of time-points including evenings and weekends and are well distributed geographically. The degree of urbanisation was not predictive either, which is reassuring because a lower coverage in urban regions could elicit a risk of transmission for some diseases.

A limitation of the study was that the participation rate in the original sample was below 80%, due to replacements and refusals that were, for unknown reasons, both more frequent than in the 1999 survey. The sample size was lower than the target, but as the design effect was also lower than expected, the accuracy of the coverage estimates was maintained. Selection bias cannot be ruled out, but the socio-demographic profile of the study population was comparable to that of the reference population. Replacement did not introduce selection bias as the coverage was the same in replacements as in the original sample population. The vaccine coverage in the study population could be underestimated as only documented doses were considered, but maximum effort was put into obtaining missing data from medical files. Children who were not officially residents in the Flanders were not sampled for this survey. As their numbers are small and their situation quite specific, it would be more useful to focus specific research on this subpopulation. Strengths of this study were that the validity of the schedule was taken into account and that the same methodology was used as for the 1999 survey, allowing for comparison of the results of both studies. Comparison to routine data is not possible at this moment, but since 2004, a web-based system (Vaccinnet) for the ordering of vaccines and registration of vaccinations is progressively being implemented in Flanders. This will create the opportunity to collect routine coverage data in the future, once fully operational and implemented.

We conclude that infant vaccine coverage in Flanders has markedly increased since 1999. It is, however, important to preserve this high coverage and even further increase it in order to achieve elimination. As children who where vaccinated outside well baby clinics were less likely to be completely vaccinated, future research should focus on the underlying reasons and possible ways to support private physicians consulted for vaccinations. The fact that we found a positive effect for both full-time employment status and income in a situation where all vaccinations were free of charge and practical barriers were very low, demonstrates that reaching families with a poor socio-economic situation remains a challenge.

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